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CARIES OF HUMAN TEETH.

BY

FRANK ABBOTT, M.D.

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By FRANK ABBOTT, M.D.,

PROFESSOR OF OPERATIVE DENTISTRY AND DENTAL THERAPEUTICS IN THE NEW YORK COLLEGE OF DENTISTRY.

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For some years I have held opinions differing more or less from those of any writer upon this subject, but have expressed them on but few occasions, except in my lectures before the class at the college. Not feeling secure in the views I entertained, however, I concluded to thoroughly investigate the subject, to either prove my theories correct or abandon them for the *facts* which I expected to establish. Very much to my gratification, my researches have confirmed my former views, with very little if any variance. Notwithstanding the fact that nearly all investigators for many years past, whose writings we have had access to, have accounted for the decay of teeth in what apparently seemed to the profession a satisfactory way, still there were practical facts which led me to view the subject differently, and which it was difficult to account for from their stand-point. These facts I have attempted to account for in this paper. I have been careful to make no statement which I am not able to prove to any one who will take the trouble to *carefully study* the specimens under the microscope.

Before entering upon the consideration of the subject, however, I wish briefly to recapitulate what has recently been discovered by Dr. C. F. W. Bödecker in the minute structure of human teeth. The reasons why I do so are, that not only are my own researches corroborative of Bödecker's discoveries, but a full understanding of the morbid processes is possible only upon a correct knowledge of the normal conditions.

Since Dr. C. Heitzmann brought to *evidence* that, with the exception of dry horny tissue (epidermis, nails, and hair), all *other* tissues of the living body were endowed with life, and that the presence of living

matter was demonstrable not only in the formerly so-called cells, but also in the basis-substance (matrix), the question arose whether a normal tooth, attached to a living body, was not possessed of this same living matter in itself. It was to be expected, judging from the phenomena of growth, of decay, of restitution, etc., that a tooth was provided with such living matter just as well as bone, which it resembles so greatly in its minute structure. But the full evidence of its presence in the tissues of the tooth was first demonstrated by the above-quoted gentleman.

The dentine is traversed by innumerable canaliculi, which ramificate both toward the enamel and the cement. Each canaliculus contains a delicate fiber of living matter, which is in direct connection with the protoplasmic formations within the pulp-cavity, with the offshoots of the cement-corpuscles, and the fibers between the enamel-rods. Every dentine-fiber sends innumerable delicate conical threads through the cavity of the canaliculus into the basis-substance between the canaliculi, where a very minute network of living matter is present, uniting the dentinal fibers with each other throughout the whole tissue of the dentine. The basis-substance is analogous to that of bone, therefore glue-giving, and at the same time infiltrated with lime-salts. Around each dentinal canaliculus the basis-substance is denser than between the canaliculi.

The cement is identical in every respect with bone; its basis-substance is traversed by larger cavities, which contain nucleated protoplasmic bodies,—the cement-corpuscles. From these arise larger offshoots in a radiated arrangement, and the protoplasmic body as well as all its larger ramifying offshoots send delicate offshoots of living matter into the basis-substance, which latter is pierced by a network of living matter, this being in uninterrupted connection with the network within the basis-substance of the dentine, the boundary being termed, formerly, the interglobular space; by Dr. Bödecker, "interzonal layer."

The enamel is provided between its polyhedral rods with very slender fibers of living matter, which also send extremely delicate offshoots into the basis-substance of the rods. Such offshoots traverse the cement-substance between the rods, and form an extremely minute network of living matter within the rods themselves, its meshes being occupied by dense depositions of lime-salts.

Again, the network of living matter of the enamel is in direct union with that of the dentine, and, on the neck of the tooth, with the network of the cement. From these facts it necessarily follows that we must consider a tooth which is normal in its structure, and in close connection through the periosteum with the jaws, as a living body; consequently, it follows that morbid processes will result in a reaction of the living matter in the tooth just as well as in bone

or any other living tissue of the body. What this reaction essentially consists in during the process termed caries I have, to my own satisfaction at least, pretty clearly *settled*. And it occurs to me that, through my researches, new stand-points have been revealed of considerable value, both for abstract science and practical use.

Methods.—The results recently obtained with regard to the minute structure of the teeth have been arrived at by *new methods*. As a matter of course, dried specimens of teeth, formerly almost exclusively in use, did not reveal any of the soft parts within the hard dental tissues. Only a frame of the tissue was left, and we may readily understand why the investigations of the carious process as yet have not passed above hypotheses and speculations.

For preparing dentine and cement, there is no better method known than slow decalcification by means of a one per cent. solution of chromic acid. In my experience large quantities of this solution are needed for a few teeth. A few drops of hydrochloric acid may be added to the chromic acid solution every other day, in order to hasten the decalcifying process. And the solution itself should be changed frequently, say once every week. The process of decalcification ought to proceed very slowly; so much so, that at least two months should be required for preparing the superficial layers of the tooth for cutting with a razor.

The teeth thus prepared I imbedded in paraffin, with a small quantity of wax added, after the water had been extracted from them by strong alcohol. The sections obtained from such specimens I stained with carmine, this being, in my experience, the best method for the demonstration of the carious condition of the tooth. After this I mounted the specimens in glycerin, diluted one-half with distilled water, and lastly inclosed them with ordinary asphalt varnish.

The enamel of teeth prepared in the foregoing manner can never be cut, because it becomes extremely brittle; therefore, I was obliged to resort for its examination to the method first practiced by Dr. Bödecker, which essentially consists in splitting *perfectly fresh* teeth, by means of a saw, into thin lamellæ, and grinding these down to the necessary thinness, always under water. The thin slices should be kept for decalcification, for twenty-four hours, in a very dilute solution of chromic acid. A saturation of this solution of over one-half of one per cent. in my opinion is deleterious to the enamel, which if *completely decalcified* shows only a *minute network* of *living matter*, as I first have observed, but no trace of the enamel-rods and prisms.

A little practice will enable any one to obtain ground specimens of a whole tooth, of such extreme delicacy that they are fit for even the highest magnifying powers over one thousand. A perfectly transparent condition should be the main property of a specimen of

a carious tooth, because only with such specimens are we enabled to study the minutest changes of the tissues to our satisfaction. Ground specimens can be stained with carmine and mounted in the same way as those obtained by cutting.

The former method of mounting specimens of teeth in damar varnish or Canada balsam has proved so very unsatisfactory, owing to the high degree of the clearing process, that it has been abandoned by our best microscopists. This method was good enough for dry specimens of teeth, in which the compartments in the dentine and enamel were filled with filth and air; but as we nowadays wish to see more of the soft tissues within the hard framework, we employ the only reliable methods as yet discovered, as described above.

Etiology.—Although the examination of a carious tooth can reveal the cause of the disease only to a limited degree, I do not hesitate to express my conviction in this respect, on the foundation of twenty years of practical experience.

There is not the slightest doubt in my mind as to the origin of caries of teeth. The first lesion under all circumstances is due to the action of an acid, which in a merely chemical way dissolves out the lime-salts from the enamel. No doubt quite a strong acid is necessary for decalcification of so solid a tissue as the enamel of a tooth. And the question often arises, Where does this acid come from?

First let us take into consideration the starting-points of the morbid process. I fear no contradiction on the part of my professional brethren when I say caries never begins on the smooth surfaces of a tooth, which are exposed to the friction of mastication, but always starts on points which, owing to their anatomical structure, form receptacles for food, etc., or on points between the teeth where, owing to want of cleanliness, decaying material can accumulate. It is therefore not to the friction between the single teeth (Salter) (which, as we know, is possible to a certain extent in the normal condition), but to the acid generated from the decaying material retained between the two flat or concave surfaces which the teeth present to each other, that the beginning of the destruction of enamel is due.

That this decaying material may be sought for and found in the food I think will hardly admit of a doubt; and, as it occurs to me, mainly in such kinds of food as through their decomposition are apt to produce an acid, not very strong, perhaps, in itself, but possessing a high degree of affinity for lime-salts, viz., lactic acid.

First among the varieties of food ranks meat, which by putrefaction may produce free lactic acid; next are the saccharine materials; and last the amylaceous, which being converted into dextrine by the action of the saliva, may be transformed, if brought in contact with putrefying meat, into lactic acid. There is no doubt that the organic portion of teeth, as it advances to the stage of decomposition

in the process of caries, plays a very important part in the formation of this acid.

Perhaps the sour decomposition is assisted locally by the action of micrococci and leptothrix; although these organisms are known to prosper only in alkaline, and not in acid fluids. These vegetable organisms are present in innumerable quantities on the healthiest gum; tartar is crowded with them. And even in the highest degrees of development of tartar *caries* is *absent*. In fact, when decayed cavities in teeth become filled with tartar, the carious process is as effectually stopped as it is possible for it to be when such cavities are *filled* in the most perfect manner, with gold or any other favorite material. Hence I do not consider the views of those authors correct who claim that micrococci and leptothrix play any important part in producing, or even supporting, the carious process.

I fully concur, however, with the views of those who claim that the resistance of the teeth against caries, owing to their amount of lime-salts, greatly varies in different people. The hue of the teeth, as is well known, is indicative to some extent of their amount of lime-salts. The microscope shows a considerable variety, with regard to the presence or the degree of density, of that layer of the basis-substance surrounding the dentinal canaliculi. E. Neumann first drew attention to this layer, which sometimes is so dense and so well defined, owing to its greater refracting power than that of the basis-substance between the canaliculi, that it may be regarded almost as a protecting sheath to the living matter within the canaliculi. This layer is well marked even in fossil teeth; it resists somewhat the action of strong acids and alkalies, but it is almost completely absent in a number of carious teeth which I have examined. I have also remarked that different teeth, treated exactly in the same manner with chromic acid solution, become soft in a markedly shorter space of time than others. The general health or constitution may have considerable influence upon the quantity of lime-salts deposited in the basis-substance of the teeth, although it has been claimed that people of so-called scrofulous and tuberculous constitutions on the average have better teeth than strong and vigorous persons.

Nations of high civilization, which inevitably leads to bodily and mental deprivation, as a rule have a greater percentage of carious teeth than those of a low degree of culture, or with no culture at all.

However this may be, the fact that caries of the teeth begins as a chemical process scarcely will, in my opinion, be questioned. On a dead tooth, natural or artificial, as well as on teeth manufactured from the dentine of the elephant or the hippopotamus, the process will remain, under all circumstances, a chemical one, assisted only by the putrefying remains of the organic material of the tooth; while

on a live tooth either acute or chronic reaction-changes take place, which I intend presently to consider.

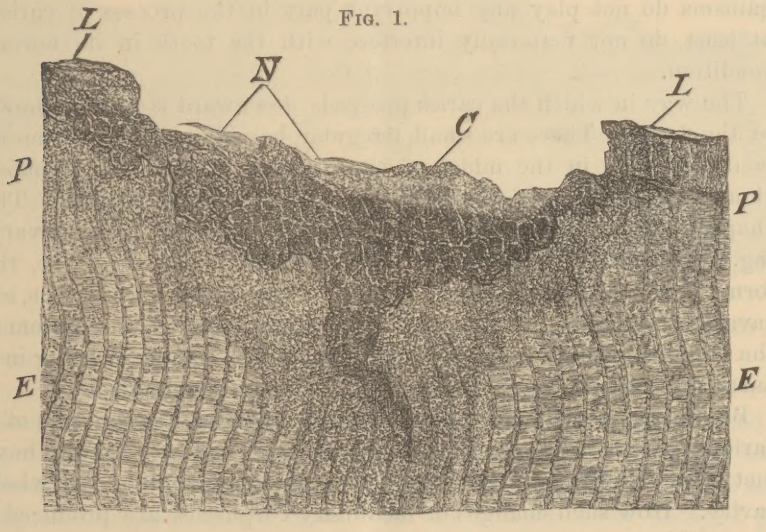
Caries of Enamel.

The clinical phenomenon of caries, in its very origin, consists essentially in a discoloration of the enamel. A whitish or grayish spot on the surface of the enamel is indicative to an experienced eye of the beginning of decay, which spot proves when touched with an instrument to be soft and crumbly. Often a brown spot is visible on the enamel as a sign of the softening process. The less pigmentation present, the more rapid is the process of decay. On the contrary, the more distinct the discoloration, the slower is the softening process. Nay, dark-brown spots may be present in the enamel for many years without being followed by softening. The brown discoloration, as such, cannot be considered as an essential feature of caries of enamel, but it usually accompanies the carious process, and does so the surer the slower the morbid process runs. On microscopic specimens we meet with decayed pits in enamel without any discoloration of this tissue. On other specimens we have a very marked orange or brown hue on the decayed part as well as in its neighborhood, and sometimes scattered specks are to be seen some considerable distance from the diseased part. The brown discoloration is located in the basis-substance of the enamel-rods, the outlines of which are much more marked than when in a healthy condition. The interstices between the rods here are plainly visible even with a magnifying power of only five hundred diameters. This power will reveal delicate beaded fibers of living matter within the interstices, which in healthy enamel can be seen distinctly with a power of eight hundred to one thousand only. Besides the discoloration, no material changes are seen on the enamel-rods.

What process the pigmentation of the enamel is due to I cannot say, but it occurs to me that we have no right to look upon this process as a merely chemical reaction upon the basis-substance of the rods. That in fact it is the basis-substance holding the pigment, and not the lime-salts deposited therein, is proven by specimens from which the lime-salts have been extracted to a considerable extent by chromic acid, and which still show the brown stain. I dare say that this brown discoloration is a strong proof of the presence of life in the enamel, as in teeth where the pulps are dead such stains never appear, nor can they be produced by artificial means. The process of decay in the enamel can best be studied on superficial erosions of the same, a sample of which I have illustrated. In this instance the brown discoloration of the decayed part was but trifling, and entirely ab-

sent in its vicinity, so that we have to consider it as a case of acute caries.

FIG. 1.



We see at *E*, *E*, Fig. 1, the unchanged enamel partly deprived of its lime-salts. Toward the periphery a zone appears in which the enamel-rods are spotted, evidently owing to their partial decalcification. Close to this and immediately below the decayed part (see *P*, *P*) a zone is visible in which the enamel is granular, and looks precisely like normal enamel from which, by a somewhat stronger solution of chromic acid, the lime-salts have been dissolved out. Here the protoplasmic condition of the enamel is re-established simply by decalcification, and there is no doubt that this is the very condition of the enamel by which the white spot is produced upon the surface while the tooth is still in the jaw. On the boundary of the enamel we see a shallow depression (*C*) filled with protoplasmic bodies, which represent either complete enamel-prisms or lumps of such prisms. All these protoplasmic formations are united with each other by delicate threads; they exhibit but a slight brown discoloration, they readily imbibe carmine, and if the specimen be stained with a half per cent. solution of chloride of gold these bodies assume a dark-blue tinge, while the unchanged enamel is but little affected by this reagent. On the outermost layer we see several flat epithelial bodies (*N*) attached to the protoplasm, which in the transverse section look irregularly spindle-shaped, and are evidently the remnants of the so-called Nasmyth's membrane, or enamel-cuticle, sunken down with the decaying protoplasm. On the level of the enamel we also recognize such flat epithelia (*L*, *L*). Beneath them on the right side of the drawing there is present a zone of decalcified enamel, while on the left side the division into protoplasmic bodies is fully accomplished.

Not a trace of micrococci or of leptothrix is visible in or above the decayed pit of the enamel, which again proves that these organisms do not play any important part in the process of caries; at least, do not materially interfere with the tooth in its normal condition.

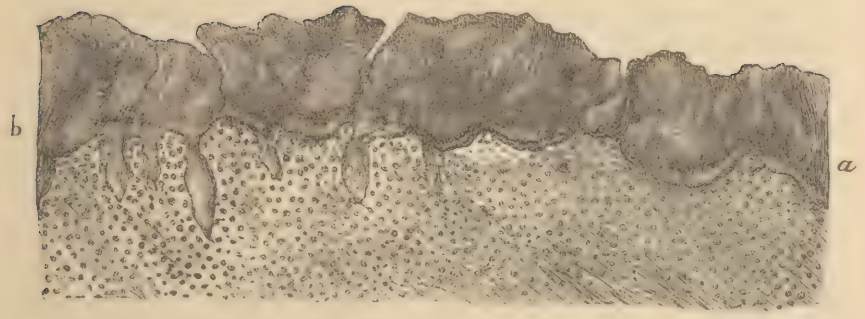
The way in which the caries proceeds downward is plainly shown by the figure. There are small, irregular, bay-like excavations on its boundary, and in the midst of the decayed part a wedge-shaped elongation is running downward into the softened enamel. The shape in which caries appears in the enamel is, however, greatly varying. Besides the wedge shape as illustrated in the wood-cut, the forms in which caries proceeds are shallow or conical excavations, excavations with abrupt walls, fissures, and grooves. On the bottom of the main excavation we sometimes see a smaller cavity, it being in a narrow or wide communication with the main decayed mass.

Besides the peculiar medullary elements forming the contents of a carious cavity of the enamel in its initial stage, I not very rarely have met with dark-brown, irregularly-shaped clusters filling the whole cavity. How such changes of medullary corpuscles are produced I am unable to say, although it seems to be kindred to the so-called *colloid* or *hyaloid* metamorphosis which we observe in other tissues, the only difference being that in caries the colloid clusters are deeply saturated with a uniform brown pigment, the origin of which, as mentioned above, is unknown.

Caries of Dentine.

Upon examining a large number of teeth with carious dentine, we are struck by conditions to the presence of which no observer has as yet drawn attention. Sometimes the dentine, attacked by caries, looks but little changed on its periphery. A narrow zone of yellowish color forms the boundary toward irregular, shallow excavations (see Fig. 2, letter *a*). At other times, besides the bay-like excavations on the periphery, there are visible elongations, cylindrical, conical, pear-shaped, or leaf-like, passing down into the dentine in varying depths (see Fig. 2, letter *b*). There is no doubt that this form of decay of the dentine occurs with the least preliminary changes of the tissues; it evidently runs a slow course, and I think I am justified in calling this form of caries chronic. It seems evident that decay of a tooth assumes an acute or chronic form just in proportion to its perfect or imperfect calcification. Dead teeth in which the pulps have been destroyed either by necrosis as a natural process, or by artificial means with caustics, very frequently run this kind of slow or chronic decay. The decay of artificial teeth, either human or ivory, in all probability

FIG. 2.



runs either an acute or chronic course, according to the amount of lime-salts infiltrated into the glue-giving basis-substance.

I have examined a piece of a hippopotamus tooth which for a period of about one year was worn in the mouth of a patient, and a spot became decayed about the size of a hemp-seed. I softened this piece with chromic acid solution, imbedded it in paraffin and wax, and cut thin sections with a razor. On the bottom of the decayed pit numerous conical spots appeared running downward into the dentine, characterized by the absence of coloring matter in specimens stained with carmine. No material change besides was observable; even the dentinal canaliculi did not look enlarged. The bottom of the carious cavity was covered with a layer of finely-granular, evidently disintegrated organic material, and above this the ordinary masses filling carious cavities in teeth, viz., micrococci and leptothrix, were visible.

In chronic caries merely a chemical process takes place, assisted by putrefaction of the organic constituents of the tooth. Here first the solution of the lime-salts of the dentine takes place, either along the bay-like excavations or in the shape of longitudinal depressions. No reaction whatever follows this process. The glue-giving basis-substance being deprived of its lime-salts shows a yellow discoloration, and only traces of the dentinal canaliculi. The basis-substance then breaks down into an indistinct granular mass, which is immediately filled with a new growth of low vegetable organisms, viz., micrococci and leptothrix.

My specimens plainly show that these organisms are not the *advance-guard* in the process of decay. The first change that takes place is exposure of the basis-substance by the chemical action of some acid, independent of the named organisms which come to view only after complete disintegration of the basis-substance. I never have seen the penetration of these organisms into the dentinal canaliculi before a thorough decalcification of the basis-substance had taken place. No doubt, however, the decayed mass itself may be crowded with such organisms which they seem to form with. In the

great majority of my specimens I have met with formations on the diseased boundary of the dentine which demonstrate a considerable degree of reaction, produced by the irritating power of the same agent to which the lime-salts of the dentine yield. In fact, this was the case in all teeth which were alive when attacked by the carious process, or rather when removed from the jaws. On the boundary of this process we see irregularly-shaped elongations running a certain depth into the tissue of the dentine. The more superficial the elongations are, the surer the morbid process may be termed a slow one; and, on the contrary, the deeper the elongations, the more certain we may be that the morbid process has advanced rapidly. The elongations mainly have the shape of fissures filled with a dark granular material, if viewed with a low power. These fissures run independently of the direction of the dentinal canaliculi; nay, very often cross them (see Fig. 3, letters *a a*). In the specimens they look as a rule as if communicating with each other, and also directly or indirectly with the decayed outer surface. Sometimes the fissures look completely isolated, though we may assume that they are separated from the communication with analogous and more superficial formations only by the method of preparation, viz., cutting into thin lamellæ.

Fig. 3.

On the surface of the carious portion of dentine we see irregular cavities filled with the same granular mass that is present in the fissures, consisting evidently of débris of the former tissue, together,

perhaps, with micrococci, and very often fine thread-like leptothrix. The more rapidly the destruction of the dentine has advanced, the more irregular islands of dentine are left on the surface (see Fig. 3, letters *b b*).

In our figure the decay evidently has proceeded rapidly; hence the remnants of the former dentine, recognizable by the presence of the canaliculi, are very small and irregular on the outer periphery of the dentine.

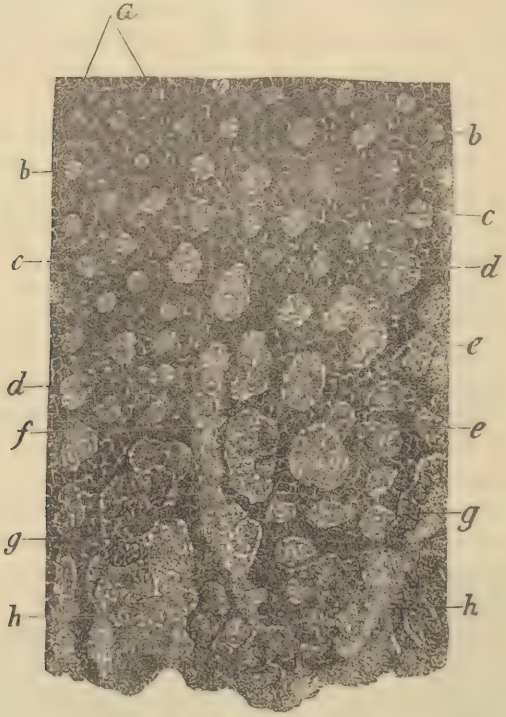
The outermost portion of the decayed part is, as a rule, brittle, and crumbles away in chromic acid specimens. Where it is left it shows a crowd of leptothrix and micrococci, without any distinctly recognizable remnants of the former tissue. On the boundary of the carious portion we, as mentioned above, meet with a yellow discoloration of the dentine, evidently produced by a chemical agent, which first dissolves out the lime-salts from the dentine, and in turn liquefies the glue-giving basis-substance. In live teeth the yellow discoloration usually takes place in the shape of longitudinal strings of different diameters, running mainly parallel with the longitudinal direction of the dentinal canaliculi. Nay, we often see single yellow strings running from the bottom of a carious cavity in the enamel through the whole depth of the dentine to the pulp-chambers (see Fig. 3, letters *c c*). The best method for demonstrating these strings is doubtless the staining of chromic acid specimens in an ammoniacal solution of carmine. While the unchanged dentine readily takes up the carmine, the strings, the deep yellow color of which is undoubtedly due to the action of the chromic acid, remain unstained.

With a power of about five hundred diameters, we recognize under the microscope, in longitudinal section of the dentine, that sometimes the yellow discoloration has taken place only within the limits of a few dentinal canaliculi, while at other times quite a number of these have undergone discoloration. Still sharper defined is the yellow discoloration on transverse sections. Here we see that mainly the canaliculi and their immediate neighborhood have taken up the yellow color in the shape of sharply-circumscribed dots, which are the larger the nearer they approach to the periphery of the decayed part. The basis-substance between these yellow spots has taken up more or less carmine. Let us examine such a cross-section with a magnifying power of one thousand diameters under the microscope.

At a certain distance from the decay the canaliculi look unchanged, and each contains the central transverse section of the dentinal fiber with its delicate radiated offshoots (see Fig. 4, letter *a*). Nearer to the decay we meet with moderately-enlarged canaliculi, the center of which is occupied by a cluster of protoplasm, the granules and threads of which have readily taken up the carmine (see Fig. 4, *b b*). One step farther we find the canaliculi considerably enlarged, to double

or treble their original size, and they are filled with yellow protoplasm, plainly exhibiting the net-like arrangement of the living matter (see Fig. 4, *c c*). The most peripheral granules send delicate conical

Fig. 4.



offshoots through the surrounding light space toward the unchanged basis-substance. In some of the enlarged canaliculi accumulations of living matter are seen fully in the shape of nuclei; sometimes two or more such nuclei may be seen surrounded by a varying amount of protoplasm (see Fig. 4, *d d*). Still nearer to the decay the canaliculi are enlarged to ten or fifteen times their original diameter, and the cavities thus produced are all filled with a partly-nucleated protoplasm (see Fig. 4, *e e*). Between the roundish cavities we meet with longitudinal cavities, arising from the confluence of several cavities in one main direction (see Fig. 4, *f*). The cavities continue increasing in size, and form large spaces, with rounded, bay-like boundaries, between which only scanty traces of unchanged basis-substance are left (see Fig. 4, *g g*). Lastly, the basis-substance has entirely disappeared, and only protoplasm is visible in its place, either in the shape of multinuclear layers or of irregular so-called medullary elements with rather faint marks of division (see Fig. 4, *h h*). Nearest to the periphery

the protoplasm does not exhibit any form elements, but looks like a disintegrated granular mass, probably intermixed with or replaced by micrococci. I say probably, inasmuch as all good histologists agree, nowadays, that the diagnosis of micrococci is possible only when they are clustered together, which is not always demonstrable even in the thoroughly-decayed mass.

We have a series of changes of the dentine fibers, and the surrounding basis-substance of the dentine before us, which I have not the least doubt is the normal procedure of the transformation of dentine by the carious process.

Fig. 5.

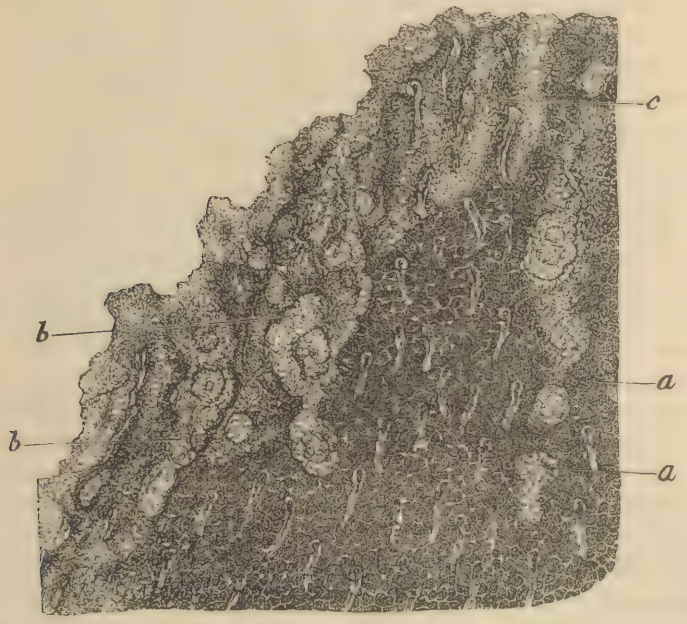


Figure 5 is an oblique section, and illustrates exactly the same changes from a tooth attacked by a less acute caries, perhaps owing to its greater solidity or more perfect calcification. Here a relatively small number of dentinal canaliculi are enlarged and filled with protoplasm (see Fig 5, *a a*). The center of the protoplasmic bodies is occupied by one or two nuclei, which look as if they originated from the former dentinal fiber. On the periphery of the dentine there are regular nests filled with protoplasmic formations of the above description, partly broken down into medullary elements (see Fig. 5, *b b*). On other parts, on the contrary, the transformation of the basis-substance into protoplasm has even preceded the changes of the dentinal fibers (see Fig. 5, *c*). The canaliculi are not noticeably enlarged; the dentinal fibers are either unchanged or slightly swollen,

and more granular than in the normal condition; while outside these we have a thoroughly decalcified and liquefied basis-substance, which means a reappearance of the network of the living matter before the stage of disintegration.

Caries of Cement.

So long as the gums are in their normal condition and position caries does not *begin* in the cement, but if the gums have receded from any cause, thus exposing the cement which covers the necks of the teeth, it may then begin to decay. I never have had an opportunity of examining primary caries of cement under the microscope, but of caries of this tissue advanced from within, viz., from decayed dentine, I have several specimens. The microscope reveals in these specimens a more or less advanced decay, which in its essential features is fully analogous to caries of the dentine when in a live condition; in other words, it is an inflammatory process. On the boundary of the caries we see, besides unchanged cement-corpuscles (see Fig. 6, *a a*), those which have been enlarged and transformed into medullary or inflammatory elements (see Fig. 6, *b b*). Nay, I have observed that the lacunæ holding the protoplasmic body were partly unchanged, while a part participated in the inflammatory process (see Fig. 6, *c c*).

The enlargement of the cement-corpuscles is evidently not due to a direct swelling of the protoplasm itself, but to a liquefaction of the surrounding basis-substance, in which the protoplasmic condition, and with this also the medullary elements which have participated in the formation of the basis-substance, reappears. The inflamed portions of the cement look granular with lower powers of the microscope, but high powers reveal the net-like structure of the living matter, and the formation of irregular polyhedral elements which are separated from each other by a light, narrow seam, this being traversed by extremely delicate uniting threads.

The history of development of bone demonstrates that this tissue originates from medullary elements, the so-called osteoblasts, which partly remain unchanged, and as such form the bone-corpuscles, while their greater part is transformed into basis-substance (Waldeyer). The history of the development of the cement has not as yet been studied, but we have good reasons for assuming that it develops in a way identical with that of bone, as both tissues are identical in their structure, and exhibit identical results when inflamed.

Dr. C. Heitzmann has drawn attention to the fact that the protoplasm of the medullary elements, when transformed into glue-giving basis-substance, does not altogether perish. It is only the fluid, non-living part of the protoplasm which, by chemical changes, is trans-

formed into glue; the living part of the protoplasm, on the contrary, remains unchanged, and is simply concealed by the refracting power of the *glue-giving* basis-substance. That this view is a correct one the investigator named has proven by the appearances in inflamed bone, and I can fully corroborate his views from my observations on inflamed cement.

Fig. 6.

Virchow's view that the bone-corpuscles swell and divide into inflammatory elements by being converted into proliferating mother cells, is in my opinion wrong. No proliferation is demonstrable in the earliest stages of inflammation of the cement. Nothing but a decalcification, and thereafter a liquefaction, of the glue-giving basis-substance takes place in order to bring to view the very same medullary elements which once have shared in the formation of the cement. The inflammatory reaction in the cement-corpuscle itself may be so slight that (as mentioned above) a part of this protoplasm may look almost unchanged, while another part toward the decalcified basis-substance gives an appearance identical with that of the surrounding liquefied basis-substance. The result of this process is a transformation of the tissue of the cement into medullary or inflammatory elements (see Fig. 6, *d d*). These remain in connection with each other by delicate threads of living matter, but at last become disintegrated, and give, together with micrococci and leptothrix threads, a decayed mass, just as well as enamel and dentine.

Results.—After having examined teeth attacked by the carious process, microscopically, from the mouths of over thirty different persons, I can sum up the results of my researches in the following aphorisms:

I. In enamel, caries in its earliest stage is a chemical process. After the lime-salts are dissolved out, and the basis-substance liquefied, the protoplasm reappears, and breaks apart into small, irregularly-shaped so-called medullary or embryonal bodies.

II. Caries of dentine consists in a decalcification, and in turn a dissolution, of the glue-giving basis-substance, around the canaliculi as well as between them. The living matter contained in the canaliculi is transformed into nucleated protoplasmic bodies, which, together with protoplasmic bodies originating from the living matter in the basis-substance, form the so-called indifferent or inflammatory tissue.

III. Cement, if attacked by caries, exhibits first all phenomena known to be present in the early stages of inflammation of bone. The protoplasmic cement-corpuscles, as well as the basis-substance after its decalcification and liquefaction, produce indifferent or inflammatory elements.

IV. The indifferent elements originating through the carious process from enamel, dentine, and cement do not proceed in new formation of living matter, but become disintegrated and transformed into a mass crowded with micrococci and leptothrix.

V. Caries of a living tooth, therefore, is an inflammatory process, which, beginning as a chemical process, in turn reduces the tissues of the tooth into embryonic or medullary elements, evidently the same as during the development of the tooth have shared in its formation; and its development and intensity are in direct proportion to the amount of living matter which they contain, as compared with other tissues.

VI. The medullary elements, owing to want of nutrition and to continuous irritation, become necrosed, and the seat of a lively new growth of organisms common to all decomposing organic material.

VII. Micrococci and leptothrix by no means produce caries; they do not penetrate the cavities in the basis-substance of the tissues of the tooth, but appear only as secondary formations, owing to the decay of the medullary elements.

VIII. In dead and artificial teeth caries is a chemical process, assisted only by the decomposition of the glue-giving basis-substance of dentine and cement.

History.

John Hunter, "Diseases of the Teeth," etc., 1778, says: "The most common disease to which the teeth are exposed is such a decay as would appear to deserve the name of mortification. But there

is something more, for the simple death of the part would produce but little effect, as we find that teeth are not subject to putrefaction after death, and therefore I am apt to suspect that during life there is some operation going on which produces a change in the diseased part."

Joseph Fox, "The History and Treatment of the Diseases of the Teeth and Gums," 1806, says: "The diseases to which the teeth are subject are similar to those which affect bones in general, and in like manner they have their origin in inflammation. The teeth differ only from bones in not possessing sufficient living power to effect the process of exfoliation."

Thomas Bell, "Anatomy, Physiology, and Diseases of Teeth," 1831, under the heading of "Gangrene of the Teeth, commonly called Caries," says: "The most common disease to which the teeth are liable is that which has hitherto been universally known under the name of *caries*,—a name which, although authorized both by English and Continental writers, is in this instance totally misapplied. It is, in fact, calculated essentially to mislead, as the disease has not the slightest analogy to true caries of bone. The perpetuation of so obvious an error as this is surely more than the most fastidious opponent of innovation could require. I propose, therefore, to substitute for it the term *gangrene* of the teeth, a word which expresses the real nature of the disease. It may be defined as mortification of any part of a tooth, producing gradual decomposition of its substance."

Farther on he says: "Still, however, the true proximate cause of dental gangrene is inflammation. And the following appears to me to be the manner in which it takes place. When, from cold or from any other cause, a tooth becomes inflamed, the part which suffers the most severely is unable, from its possessing comparatively but a small degree of vital power, to recover from the effects of inflammation, and mortification of that part is the consequence. That the bony structure of the teeth is liable to inflammation, appears not only from the identity of the symptoms which take place in them, when exposed to causes likely to produce it, with those which are observed in the other bones when inflamed, but more conclusively still from the fact, already mentioned, that teeth are occasionally found in which distinct patches, injected with the red particles of blood, have been produced by this cause after the continuance of severe pain."

Dr. E. Magitot, "Treatise on Dental Caries" (English translation by Dr. T. H. Chandler, 1878), in his general conclusions says:

"I. Dental Caries is a purely chemical alteration of the enamel and ivory of the teeth. Dental Caries is one. The varieties of form and color depend upon simple secondary variations in the nature of the altering cause, the progress, and the duration of the malady.

"Lesions of the enamel consist, after the removal of the cuticle, in

a purely passive chemical disorganization of the prisms composing its tissue.

"Lesions of the ivory, consisting likewise in a chemical decomposition of its elements, may sometimes, though rarely, remain passive; but most frequently they determine in the tissue phenomena of reaction that manifest themselves by the appearance of a cone or white zone, formed by a mass of canalicules obliterated in consequence of a formation of secondary dentine.

"The tooth attacked by caries does not remain passive and inert, but may in some measure undertake to resist its action by the phenomena of condensing dentification of the ivory.

"The agent of dental caries is the saliva, become the medium of acid fermentation, or the vehicle of foreign substances susceptible of altering directly the tissues of the ivory and the enamel. Caries can be caused artificially by imitating the conditions of alteration that the mouth itself may present. It then offers the same characteristics as the morbid caries, with the exception of the phenomena of the organic resistance.

"The intimate mechanism of the production of caries is a simple solution of the mineral and calcareous salts which enter into the constitution of the enamel and of the ivory, by the agent of new formation."

Drs. Leber and Rottenstein, "Dental Caries and its Causes," 1873, say: "We have already several times remarked that the action of acids alone does not account for all the phenomena which appear in caries of the teeth. It is true that acids, even very much diluted, can attack the dental tissue; but we find in their mode of action differences which distinguish them from the phenomena and from the progress of dental caries. The acids attack first the enamel and rapidly change it to a chalky mass; later on their action is felt in a marked manner upon the dentine, which becomes more transparent, and, in fine, as if cartilaginous, by the very slow but progressive loss of its calcareous salts.

"Caries, on the contrary, proceeds slowly in the enamel; it is much swifter in the dentine, where it proceeds promptly along the canaliculi. This difference of progress must be attributed to the participation of the fungi in the work of the caries. The elements of the fungus glide easily into the interior of the canaliculi, which they *dilate*, and thus favor the passage of the acids into the deeper parts; these same elements cannot penetrate a compact enamel, or at least they enter more slowly, and only when the elements which form it have been greatly changed by the action of acids. . . . For them (the leptothrix) to be able to penetrate thus, it is necessary that the teeth be in a suitable condition; the enamel and the dentine must have lost their density by the action of acids. It seems that the fungi are

not able to penetrate an enamel of normal consistence. The dentine itself, in its normal condition of density, offers great difficulties to their entrance, and we are not yet sure that the leptothrix could triumph over this resistance. . . . We cannot decide at present if the leptothrix is able to penetrate sound dentine when from any abnormal circumstance it happens to be denuded; but if the enamel or the dentine are become less resistant at any point through the action of acids, or if at the surface of the dentine a loss of substance has occurred, then the elements of the fungus can pass into the interior of the dental tissues and produce by their extension, especially in the dentine, effects of softening and destruction much more rapid than the action of acids alone is able to accomplish."

Carl Wedl, "Pathology of the Teeth," 1872, says: "It was quite natural to transfer to the teeth the signification implied in the expression 'Caries of bone;' indeed, the fundamental phenomena, namely, the destruction of the hard tissues, offered a striking analogy. In their development, however, the two processes by no means present such an identity. Caries of bone, as is well known, is an inflammatory process (osteitis) which originates in the soft parts of the bone and erodes its hard tissue. This is not the case with the carious process in the teeth, which commences in the hard tissues and spreads to the vascularized and nervous dental pulp. Upon close investigation the latter process is found to be so entirely distinct from the former that the attempt has repeatedly been made to expunge altogether from the nomenclature of diseases of the teeth the expression 'Caries of the teeth.'

"Notwithstanding the fact that our knowledge is advancing, unquestionably, with the continual addition to the auxiliary means at our command for carrying on the work, it must, however, be acknowledged that a theory with regard to caries with a thoroughly scientific basis in all its details is still wanting. . . .

"In sections made in a direction transverse to the axes of the radiating dentinal canals, a greater or less number of canals are met with whose limiting walls (the so-called dentinal sheaths) describe unusually large circles, and whose cavities are replete with a mass which has in some places a homogeneous, in others a molecular appearance, and forms convex projections beyond the surface of the section. The transverse diameters of the widened and filled canals vary, some being at least three times as large as others. The intertubular tissue presents a *molecular cloudiness*, and is beset with grains having the appearance of fat. In sections made parallel to the long axes of the canals they are quite clearly seen to be unequally filled by the foreign mass, since they present manifold varicosities and constrictions, which also explain the variations in the diameters of the widened canals. . . .

"Since we know that an interchange of material takes place in the dentine and cement during life, as is proved by the occurrence of atrophies, hypertrophies, and new formations, and that the dentine possesses a degree of sensibility, we cannot reject absolutely the idea of a reaction on the part of both hard tissues against the effects of external agents.

"Some authors seem to have had an intimation of this idea, since they were inclined to consider the textural changes in carious dentine as vital processes. There can be no doubt that the sensibility, sometimes increasing to actual pain, of the dentine, when deprived of its protecting covering, is a vital action, and that this becomes diminished when the most sensitive, the peripheral portion, is destroyed by an external agent. These facts, however, are by no means sufficient to enable us to draw a conclusion in favor of the reactionary power of dentine in parts which are attacked by caries. . . .

"In consequence of the decomposition of the secretions, acids are formed which extract the calcareous salts from the hard tissue, and give rise to a disintegration of the affected portions of the latter, in which no inflammatory reaction occurs."

Tomes, "System of Dental Surgery," 1873, says: "Although dental caries has been investigated and described by all who have written upon the subject of Dental Surgery, from the earliest period when disorders of the teeth first attracted attention down to the present time, yet it can scarcely be said that the nature of the disease is perfectly understood, for even now two hypotheses prevail. In one the disease is assumed to be no disease whatever, but merely the result of chemical solution of the dental tissues, and therefore dependent both in its origin and its progress on the uncontrolled action of physical and chemical laws. According to the other hypothesis, the fact that teeth are part of a living organism, if not essential to the origin of the mischief, at all events profoundly modifies its progress. Much has been written in favor of each of these views, and yet the subject cannot by any means be held to be settled."

In the appendix to this work we find the following "conclusions," viz.:

That caries is an effect of external causes in which so-called "vital" forces play *no* part. That it is due to the solvent action of acids which have been generated by fermentation going on in the mouth, the buccal mucus probably having no small share in the matter; and when once the disintegrating process is established at some congenitally defective point, the accumulations of food and secretions in the cavity will intensify the mischief by furnishing fresh supplies of acids.